MCAT

Meter Class Autonomous Telescope

Dr. Sue Lederer

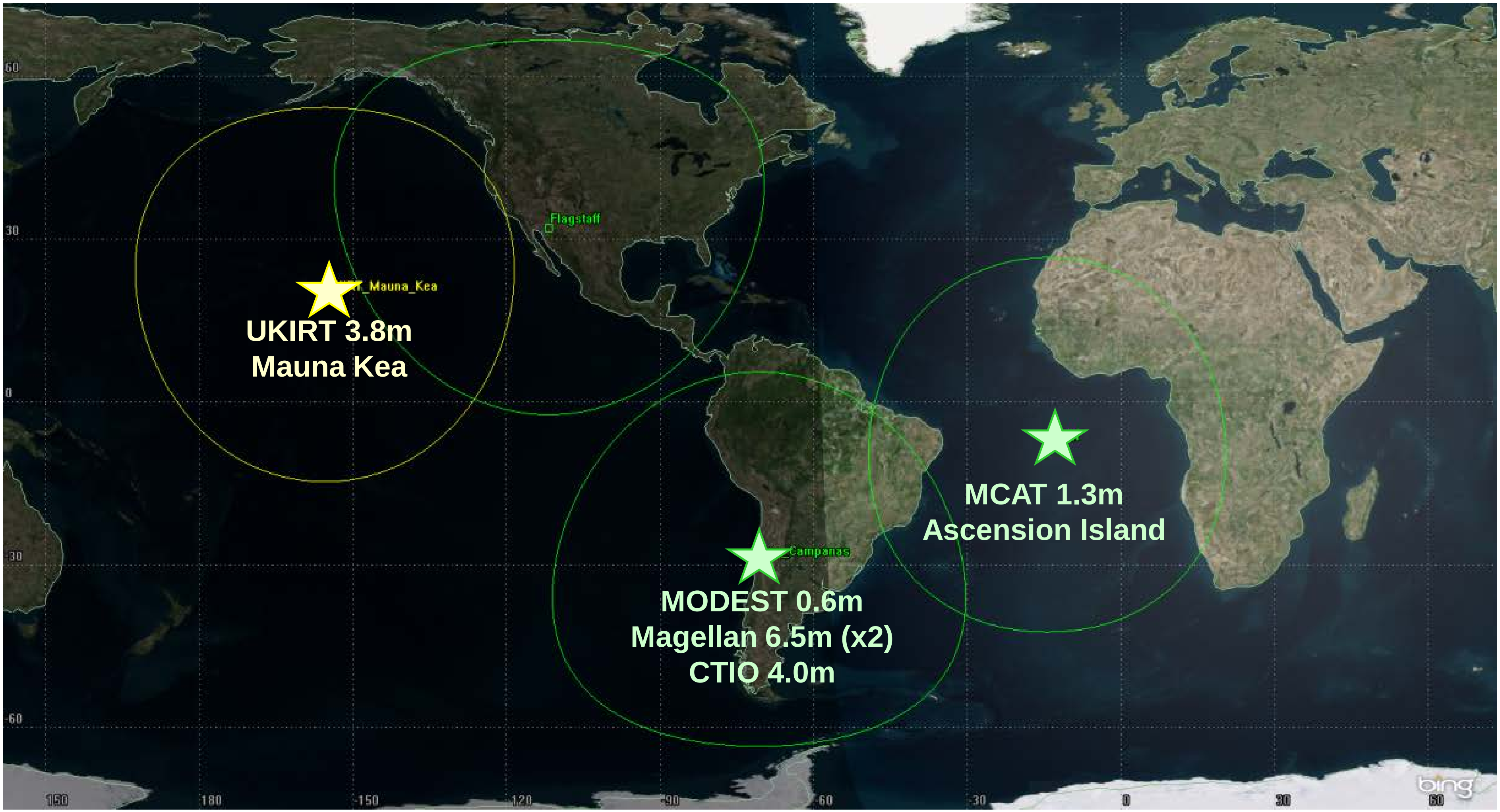
National Aeronautics and Space Administration

Orbital Debris Program Office

NASA/AFRL joint project

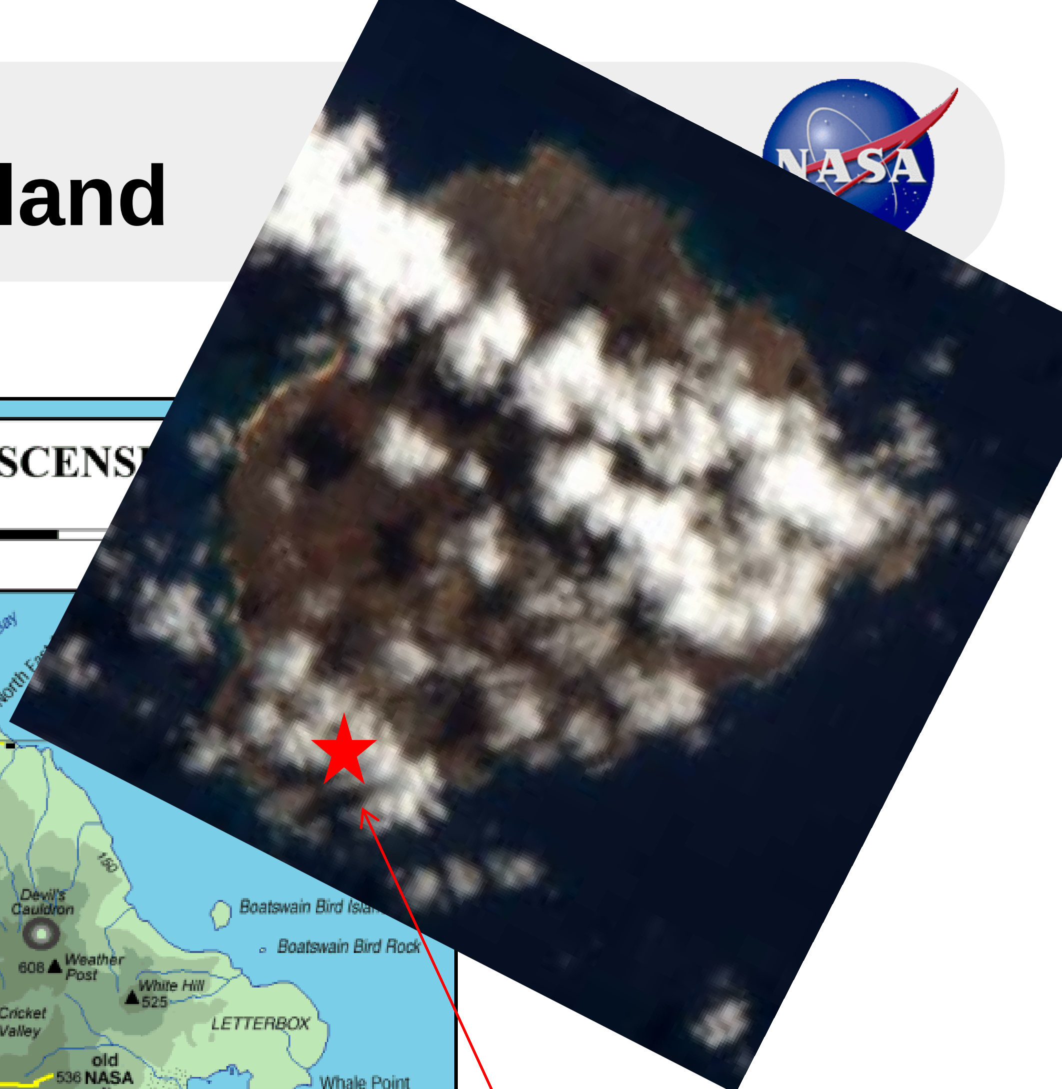
- **NASA**
  - Principal Investigator: ***Dr. Susan Lederer***
  - Project Management & Logistics: ***Lisa Pace***
  - ODPO Office: ***Gene Stansbery***
  - JETS contractor staff: ***Dr. Heather Cowardin, Dr. Brent Buckalew, Dr. James Frith***
- **Air Force Research Laboratory (AFRL)**
  - Schafer Corp: Hardware integration: ***Tom Glesne***
  - Pacific Defense Solutions, Integrity Applications Inc.: ***Riki Maeda, Dennis Douglas, Daron Nishimoto***
  - AFRL Maui: ***Paul Kervin***
  - Air Force Nuclear Weapons Center (AFNWC):
    - Architectural contract
- **Euclid Research/ U British Columbia**
  - ***Dr. Paul Hickson***
- **Air Force 45th Space Wing**
  - Detachment 2 Ascension Auxiliary Airfield, Ascension Island
  - Cape Canaveral Air Force Station
    - Construction contract

Optical and IR Telescopes used by the NASA debris office




Location of
NASA MCAT
(7^{o} 58’ S; 14^{o} 24’ W)
~350’ Elevation; Google Earth Image)

Ascension Island



MCAT site

Project Overview

- **Collaboration between NASA, Air Force 45th Space Wing, and Air Force Research Laboratory (AFRL) Maui Optical Site (AMOS)**

- **MCAT Goal: Statistically characterize under-sampled orbital regimes**
  - Geosynchronous and near GEO altitudes
  - LILO, i.e. Low inclination Low Earth Orbit (LEO)
    - Evening and morning twilight
  - Share Metric Observations with DoD

- **MCAT Objectives:**
  - Monitor and assess orbital debris environment by ***surveying, detecting***, and ***tracking orbiting objects*** at:
    - LEO, MEO, GTO, GEO altitudes
    - Debris as small as 20-30 cm in GEO should be detectable
    - GEO debris surveys
      - ➢ Share Obs with Air Force Space Command (AFSpC)
  - May participate in JSpOC (*Joint Space Operations Center*) follow-up or hand-off activities

- **Ascension Island location enables access to under-sampled low inclination orbits and new GEO longitudes**
  - Existing technical staff for “caretaker” support
  - Automated data analysis at site
  - Low data transmission requirements – transmit results, not data

(7º 58′ S, 14º 24′ W)

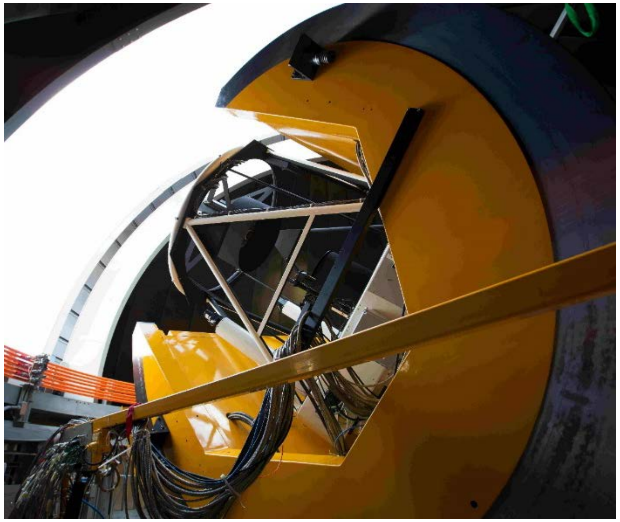
Operational Concepts to attain Objectives (BIG PICTURE)

1. GEO Sweep/ GEO Follow-up:	2. Catalog or Object-of-Interest Tracking:	3. Orbit Scan (LEO mode):	4. Stare – Detect – Chase:	5. Coordinated Observations:
TDI mode matches GEO motion to sweep GEO longitudes; *follow-up specific targets for further characterization*	*Target specific objects for testing or characterization*	*Define rate track by a given expected orbital rate*	*Object crosses Field of View, its motion calculated, chase at calculated rate of motion*	***I. Optical-Optical*** *miniCAT* ***II. Radar-Optical*** *C-band radar on Ascension;*

- **5 Modes of data collection**
- **Survey: Modes 1 & 3**
- **SSA: supported most through modes 2 & 3**
  - Mode 2 to determine individual object characteristics/orbits
  - Mode 3 for rapid follow-up after break-up event
- **Data to be transferred off island via DSCS**

Meter Class Autonomous Telescope (MCAT)

- **1.3-m DFM telescope**
  - 1.3m double horse-shoe DFM telescope
    - Fast tracking smoothly through zenith
  - 7-m fast-tracking Observadome (GEODSS equivalent)
  - Spectral Instruments camera
    - TDI (time-delay integration) enabled
    - **41' x 41' FOV** (0.957° diagonal)
    - BVRI, g'r'i'z' broadband filters

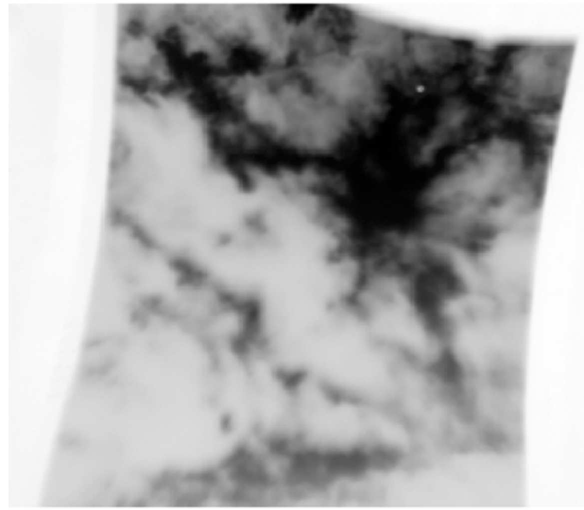


- **0.4m Mini-CAT**
  - 16" (0.4m) Officina Stellare telescope
    - Atlas focuser
  - LEO tracking Astelco mount
  - Finger Lakes Proline camera, e2V chip
    - **44' x 44' FOV**
    - 1.3" per pixel (vs. 0.6"/pix MCAT)
  - Centerline Filterwheel
    - BVRI, g'r'i'z' broadband filters

→ Simultaneous observations with MCAT in 2 filters

(7° 58′ S, 14° 24′ W)

Instrumentation: Weather, Clouds & All-Sky



Weather equipment

- **5 weather station/sensors**
  - Temperature, Pressure
  - Wind speed average & direction
  - Humidity, dewpoint
  - Rain sensors
  - Cloud sensors
- **All-Sky cam**
  - View of the whole sky to determine cloud location and best observing strategy
- **FLIR Infrared Cam** (on MCAT)
  - 40deg FOV mounted on MCAT for real-time views of clouds as MCAT takes images

Sky Brightness

- Sky Brightness average (no moon): 21.3 – 21.7 mag/sq-arcsec

Winds

- 17-20mph average sustained winds, SE/SSE

Seeing

- Initial estimates: 1.5 – 2"

MCAT Timeline

New since IADC 2015: **in bold**

Systems Testing	Construction	Acceptance Testing	Full Integration/ Data Collection
• July 2013: Telescope testing • Aug 2013-June 2014: Software/Hardware integration testing	• Sept 2014, Ground-breaking • Sept-March/April 2015: Main facility construction • **March-April 2015: Dome installation** • **April-June 2015: Telescope installation**	• **June 2, 2015: Engineering First light** • **June17: Camera failure** • **SAT for all except Camera-specific tasks** • **Aug: 1st Light alt camera for debris tracking, lightcurves** • **Nov: Si Camera fix** • **Dec 2015: SI Camera**	• **Dec 2015: Begin fully integrated systems testing** • **Jan 2016: Remote Data collection begin** • **Apr/May 2015: miniCAT installation testing (16" telescope)** • **Full operations expected 20+ years**

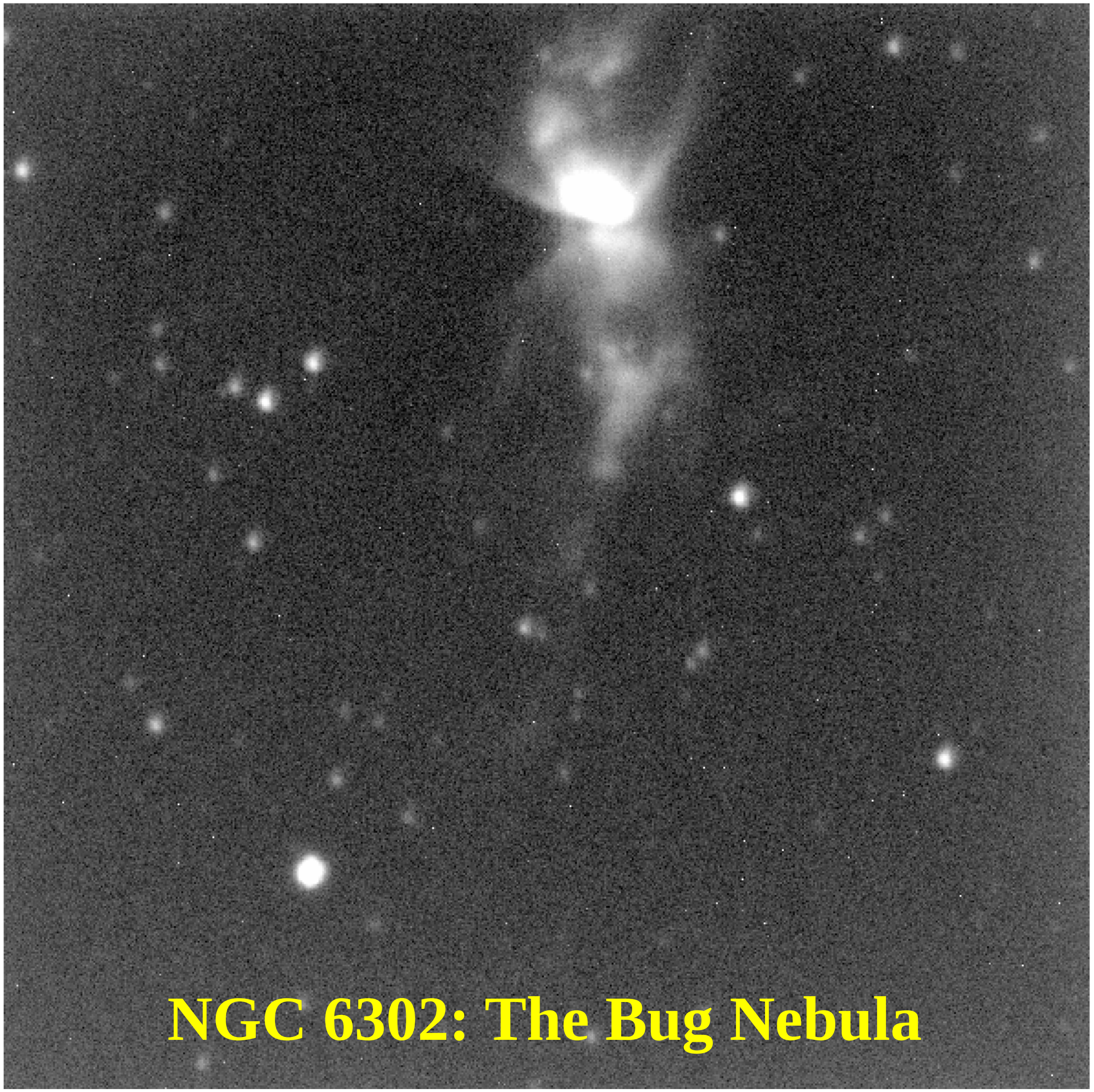
Instrument Commissioning

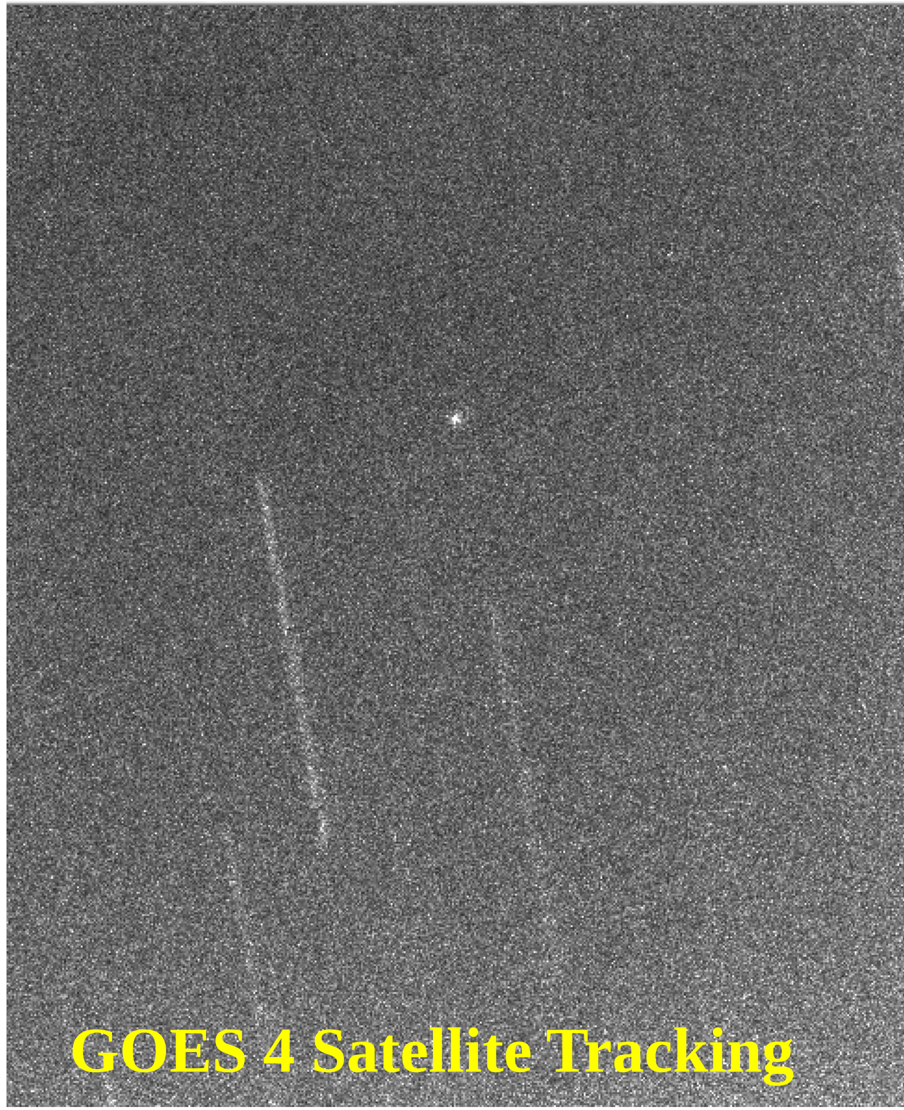
- **Finger Lakes Fast-read out (alternate camera)**
  - Originally purchased for the DIMM seeing monitor measurements
  - Electronically cooled (55C below ambient)
  - 3' x 3' FOV
    - Small format, but fast read-out, electronic shutter (4 MHz or 10 MHz)
    - **Lightcurve studies** of known objects
  - Instrument commissioning Aug 2015
- **SI camera (prime camera)**
  - Cryo-cooled (-110C)
  - Instrument commissioning Dec 2015
  - 41' x 41' FOV
    - Survey, Object characterization

- **FLIR Infrared sky-cam mounted on MCAT above secondary mirror**

First Light: Aug 25, 2015

FLI fast-readout camera



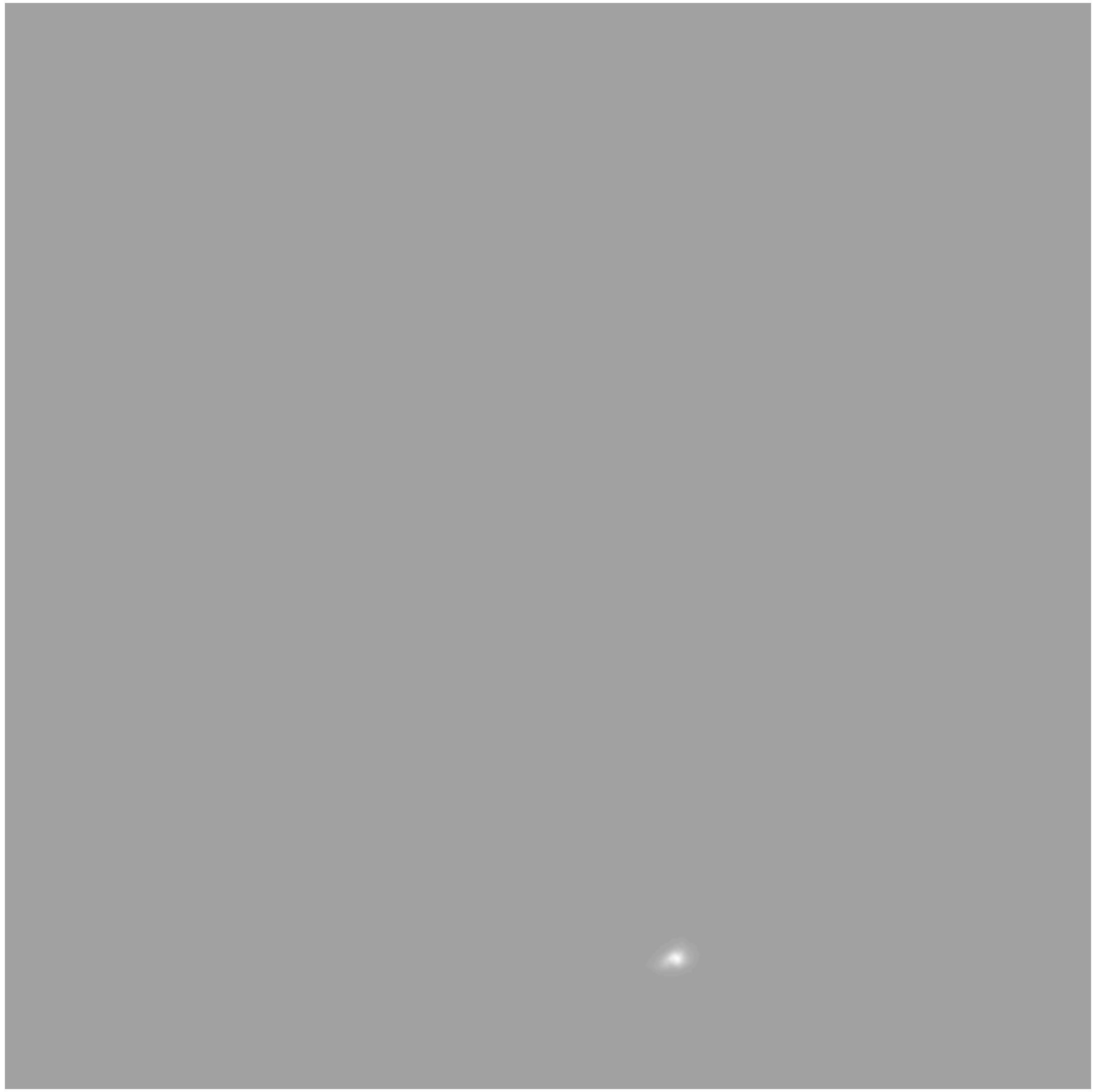


LEO pass of Transit 4a R/B debris

FLI fast-readout camera

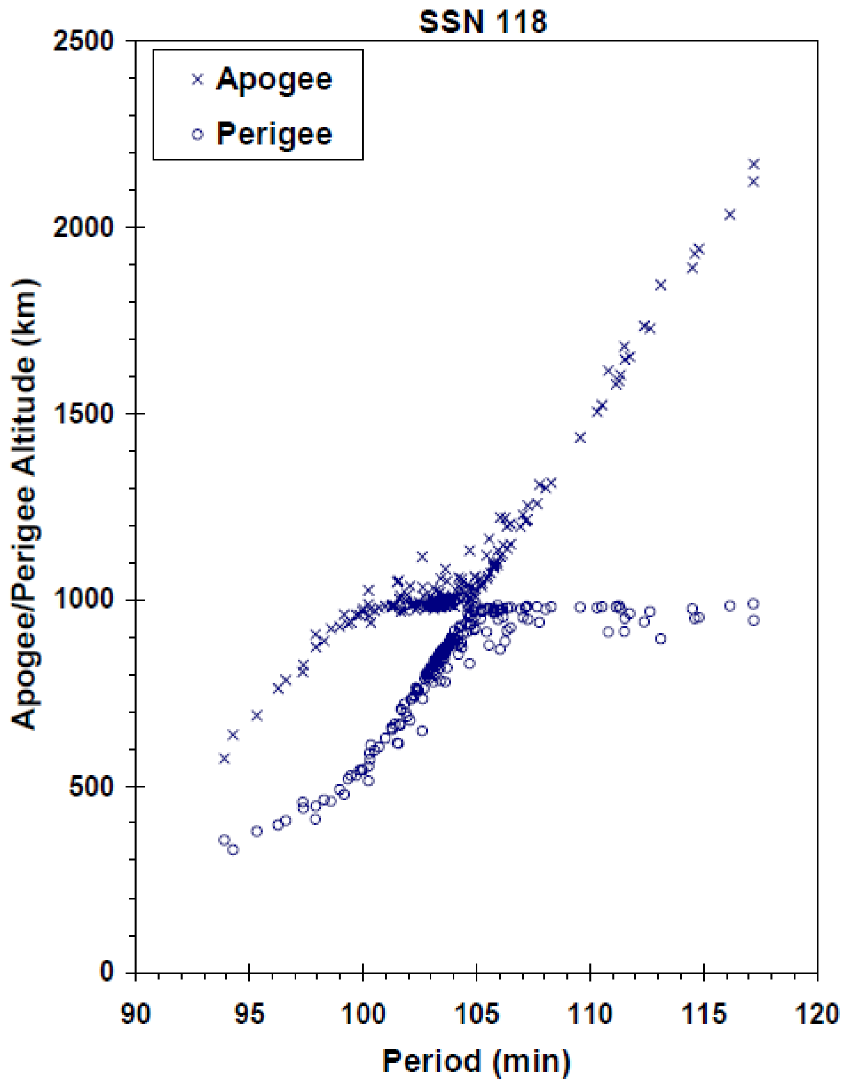
- **MCAT tracking LEO**

- **Animation (right)**
  - FLI fast camera
  - 2015 Sept 03
  - ~10 second pass
  - 1 sec exposures
  - 2 images show star trails



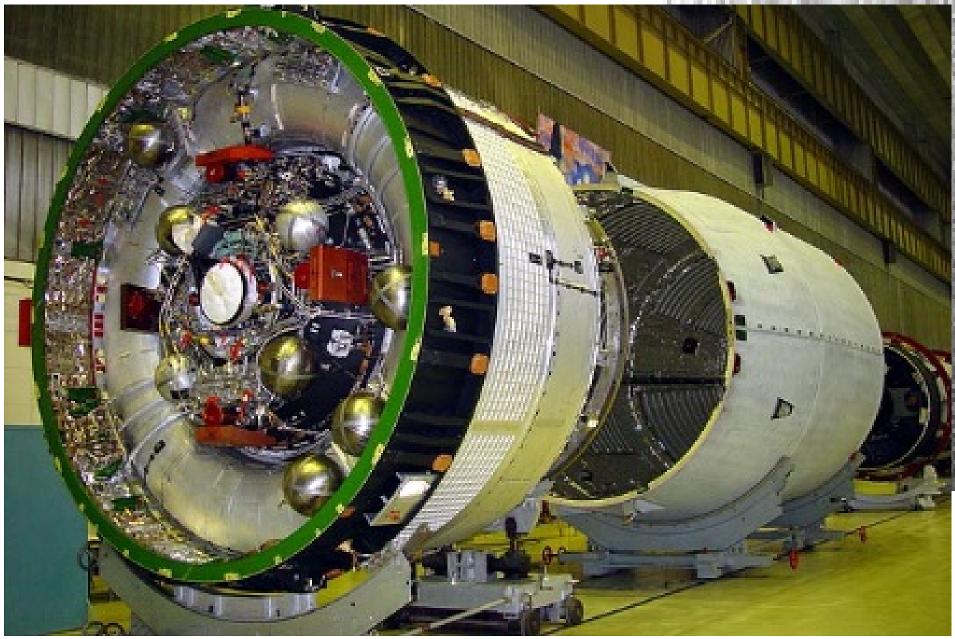
Transit 4A Rocket Body

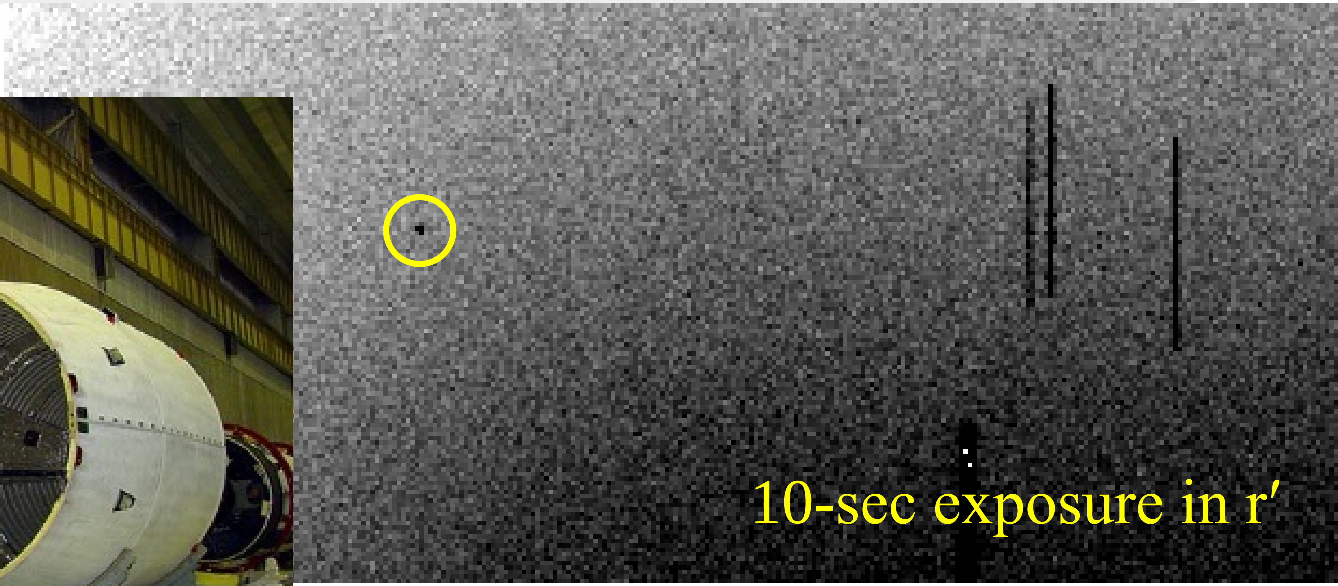
- **First known satellite fragmentation**
  - Ablestar stage successfully deployed 3 payloads
    - Transit 4A
    - Injun
    - Solrad3
  - LEO breakup, June 29,1961
  - 77 min after orbital insertion
  - Didn't vent the remaining 100kg of propellant upon payload separation
  - Fuel venting recommended after this event!
- **Fragments cataloged**
  - 296 fragments cataloged
  - 181 still in orbit in 2008



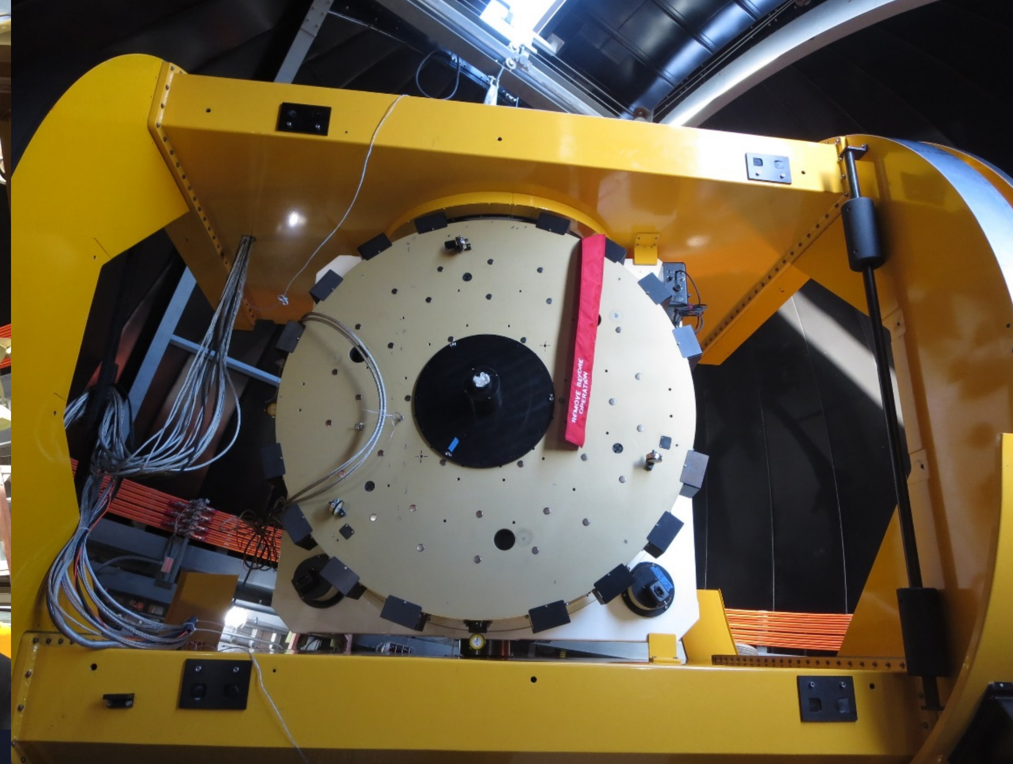
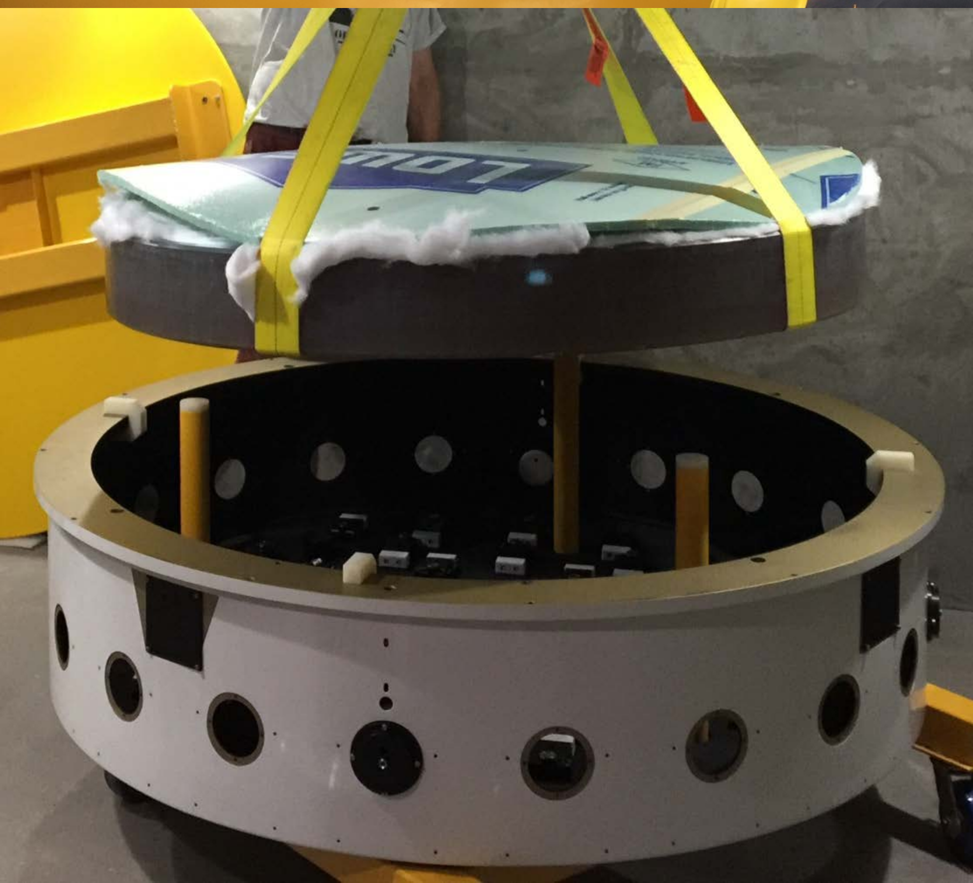
Prime SI Camera Commissioning Dec 2015

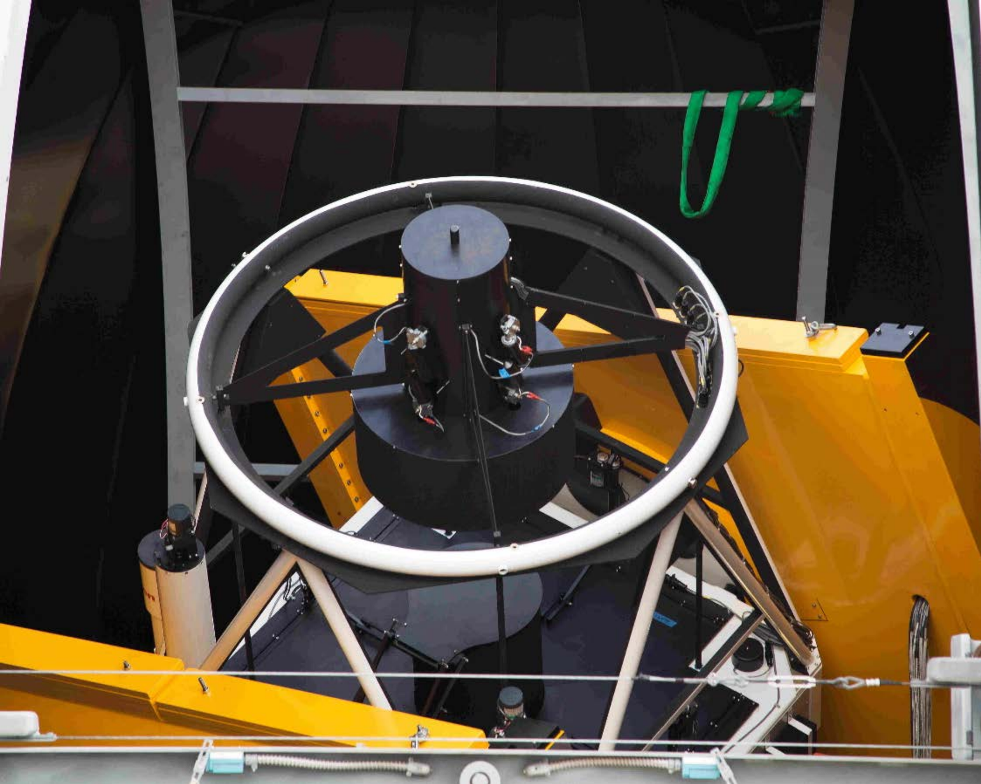
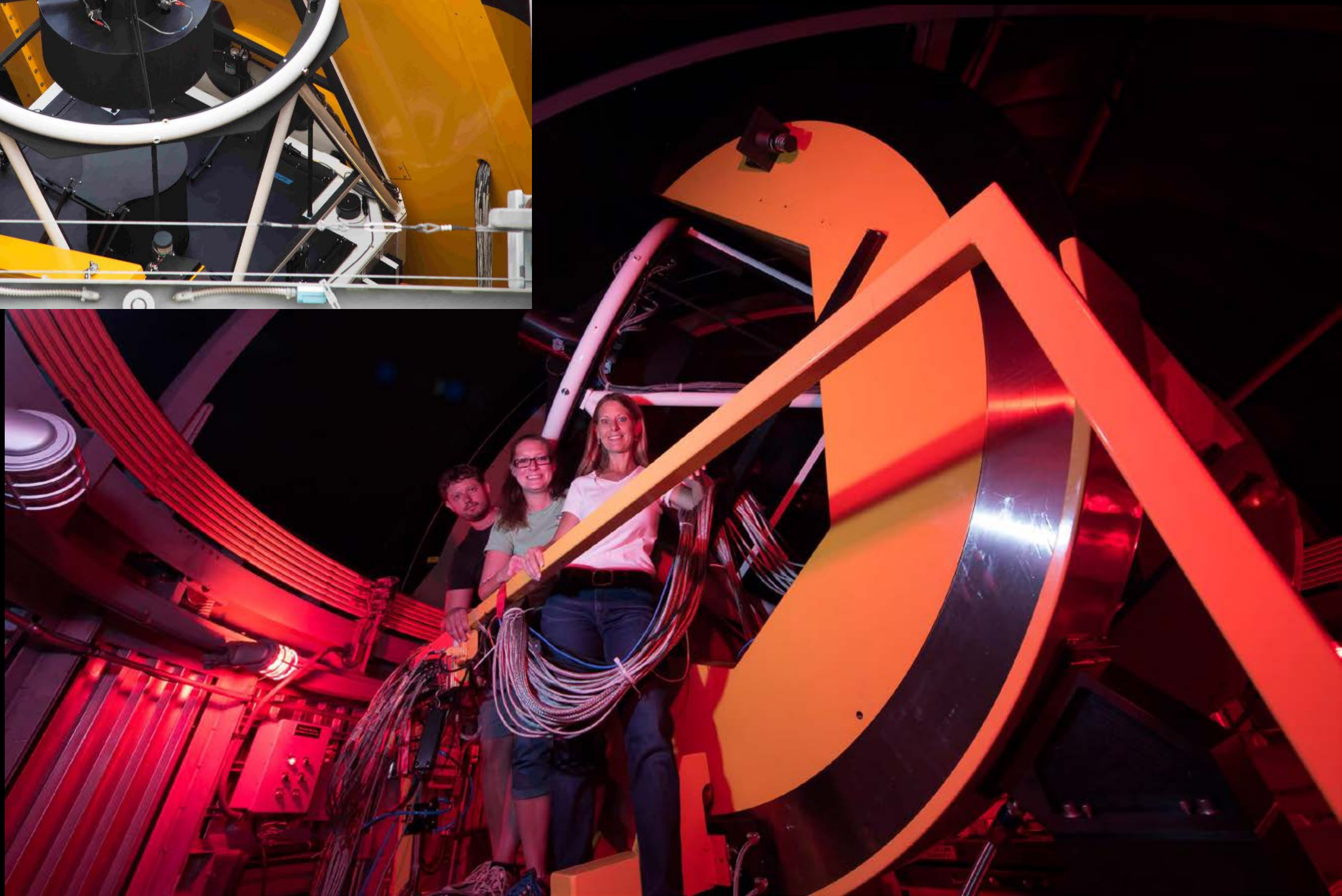
BRIZ-M Rocket Body Breakup Identified Jan 20, 2016





- Launched Dec 13, 2015, broke up 3:50 UTC Jan 16, 2016
- Inserted into GEO orbit (33,400 x35,800km orbit)
- Surveys to detect debris associated with the breakup cloud with both MCAT and UKIRT

MCAT
NASA
ASCENSION ISLAND

UKIRT

United Kingdom Infrared Telescope

Mauna Kea, Hawaii

United Kingdom Infrared Telescope (UKIRT)

Thirty years of operations supporting advanced astronomical science.

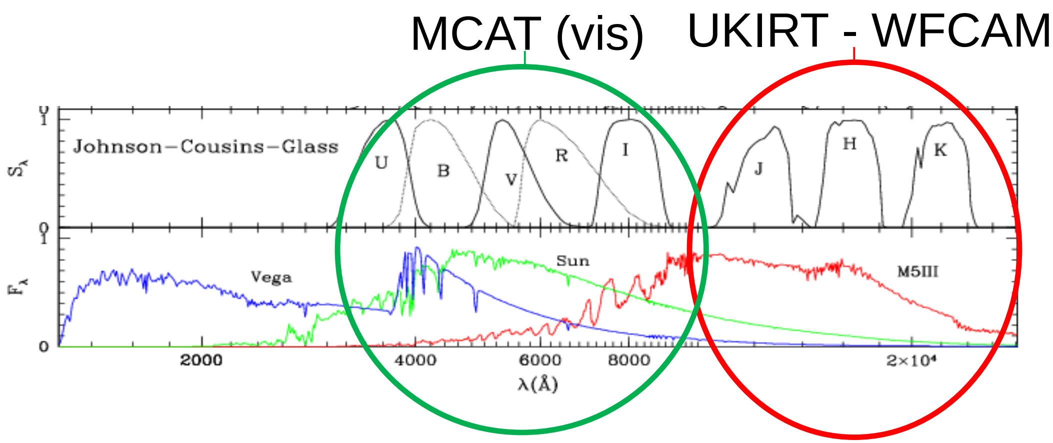
- **UKIRT**
  - 3.8 meter telescope
  - One wide-field camera (0.8 sq. deg Field of view), 4 imager/spectrometer cameras
  - Optimized for near-mid infrared (0.8 – 25 μm)
- **Location**
  - Mauna Kea, Big Island, Hawaii: 13,800 feet (4200m) above sea level
  - Arguably the best ground based infrared observing location in the world

UKIRT Contract

- **UKIRT Management**
  - Lockheed Martin contract, PM Matt Bold matthew.m.bold@lcmo.com
  - PI: Rick Kendrick
  - U Arizona subcontract for daily operations
- **NASA HQ Contract currently**
  - Contract under HEOMD, Jason Crusan, COR
  - Principal Investigator and Technical COR: Dr. Sue Lederer (NASA JSC) susan.m.lederer@nasa.gov
- **Lockheed/Univ of Arizona is building a consortium of partners to support UKIRT**
  - Astronomical studies
  - Debris studies

UKIRT Instrumentation

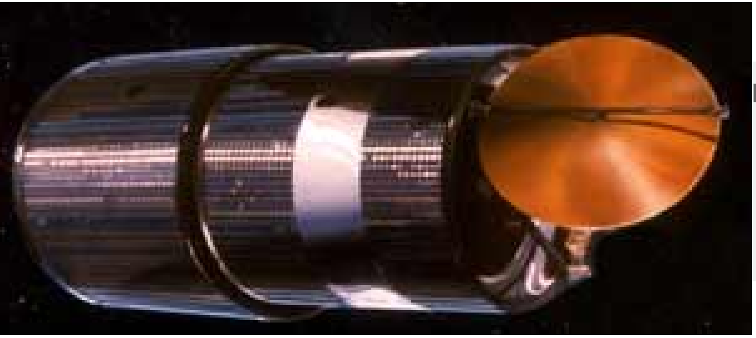
- Increases **spectral** and **geographical coverage** of GEO belt
- **Instrumentation**
  - Wide Field Camera: **WFCam** photometry
    - ZYJHK (0.8-2.4 μm)
  - Two key Imager/spectrometers
    - **UIST** (1-5 μm)
    - **Michelle**: (8-25 μm)
- **IR + Vis photometry + albedo**
  - provides insight into material types and sizes



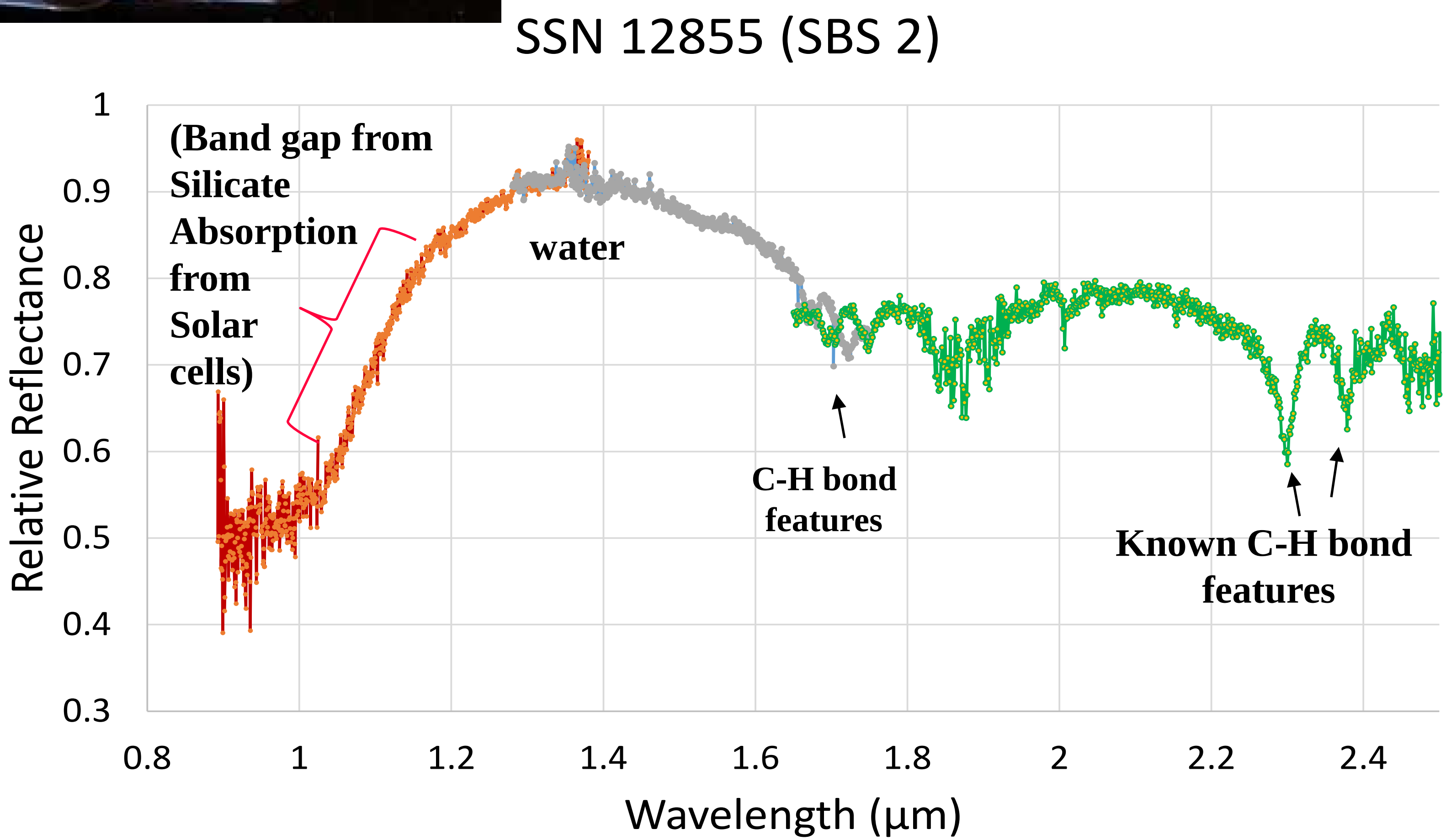
- **Spectra**
  - characterize surface material of orbital debris and targets of interest
  - Thermal characteristics

UKIRT Science

- **What can UKIRT do for us?**
  - **UIST Spectrometer/Imager** 0.85 – 5 μm
    - Near infrared absorption bands can be used to identify debris materials of spacecraft by modeling with spectral database input
      - ➢ Distinguish silicon band-gap signatures of Solar Panel near 1 μm
  - **Michelle spectrometer/imager** 8 – 13 μm thermal imaging and spectra
    - Can be used to estimate size of debris
  - **WFCam (imager) & UIST spectrometer/imager** 0.85 – 2.5 μm spectra
    - Space weathering study of HS-376 buses, cylinders covered in solar panels, taken of satellites launched over a 2 decade window
    - GEO survey for debris population statistics
    - Survey of BRIZ-M rocket body Jan 16, 2016 breakup for 15 nights



HS 376 bus

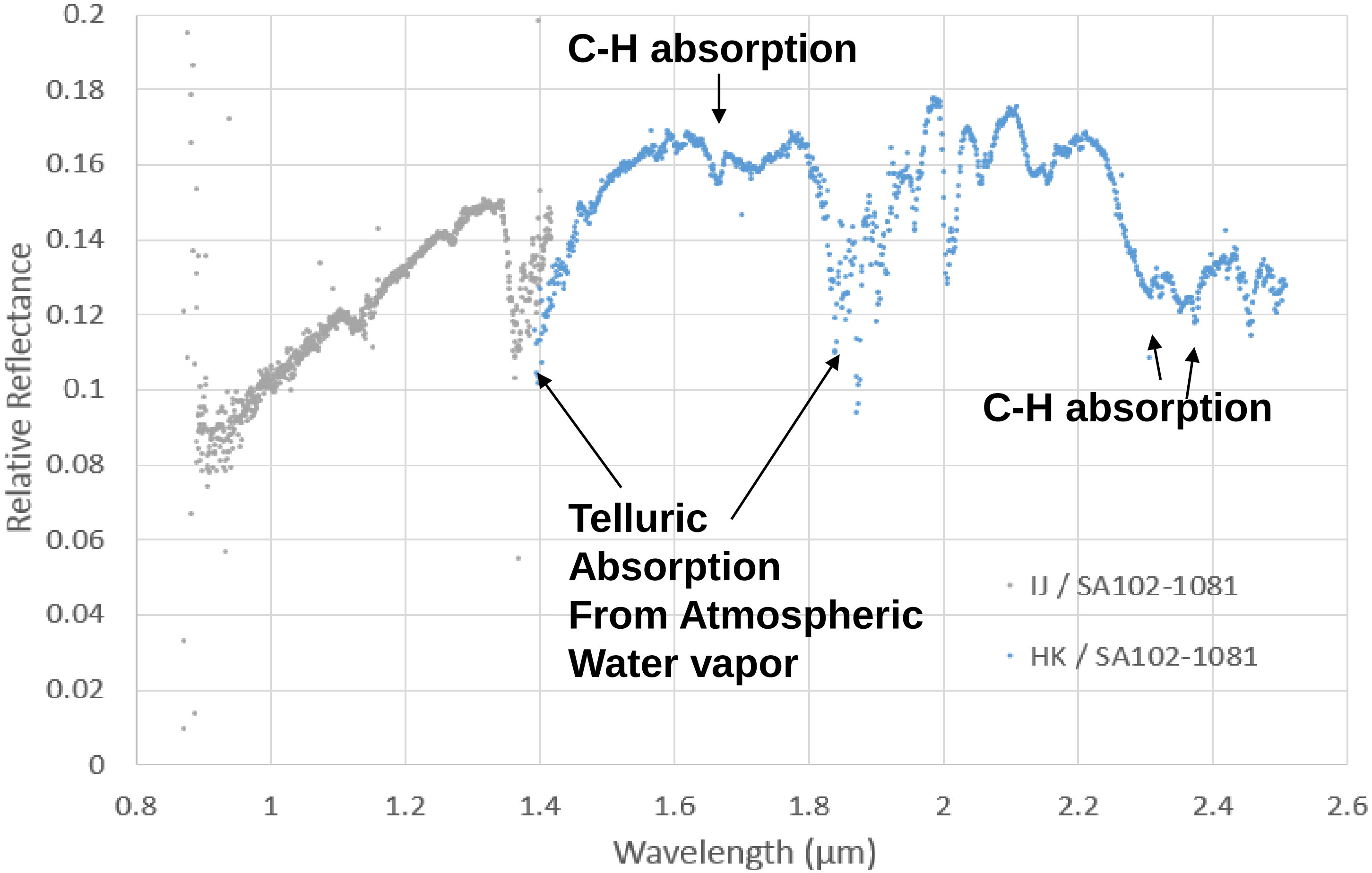


- **Spectra can be used to determine materials comprising the observed object**
- **These buses are a good baseline to identify lines from solar panels**

Rocket Body

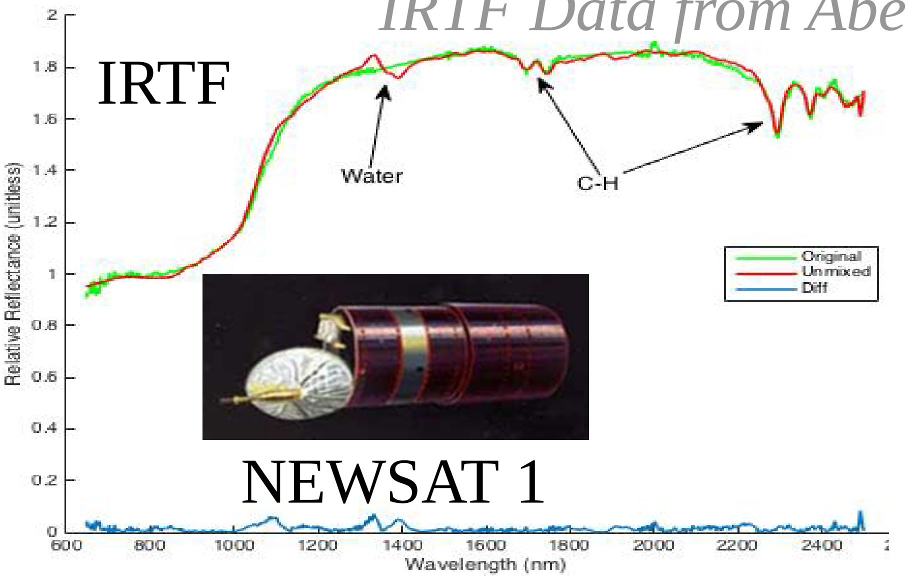
- **IUS Upper Stage**
  - Carbon-carbon epoxy
  - White paint
  - MLI

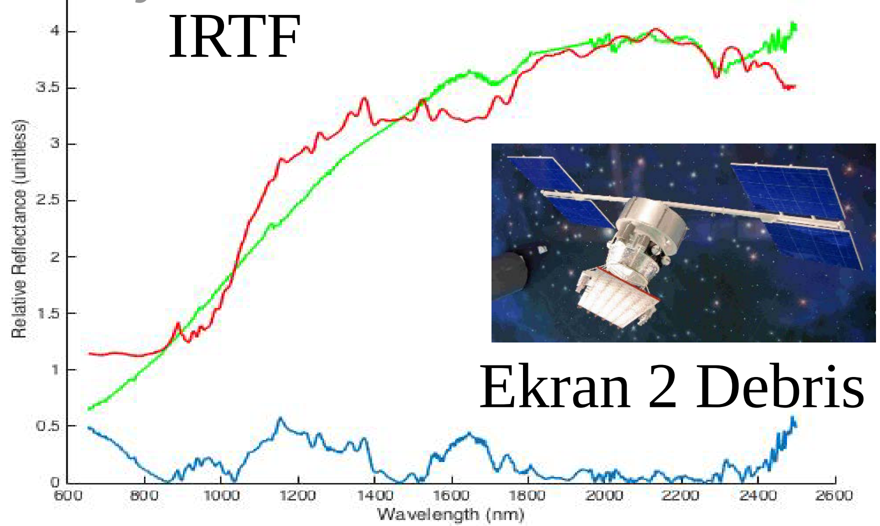
- **1.65 & 2.3 µm**
  - C-H absorption
  - Indicative of white paint

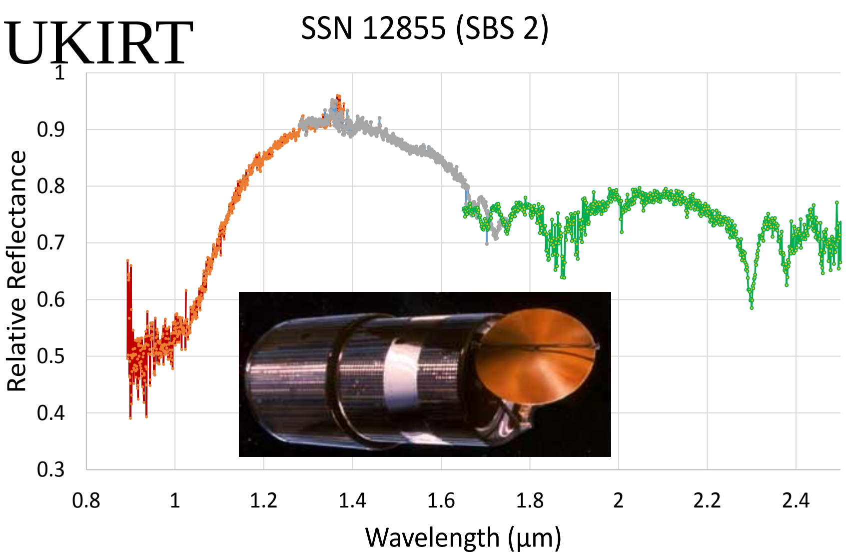


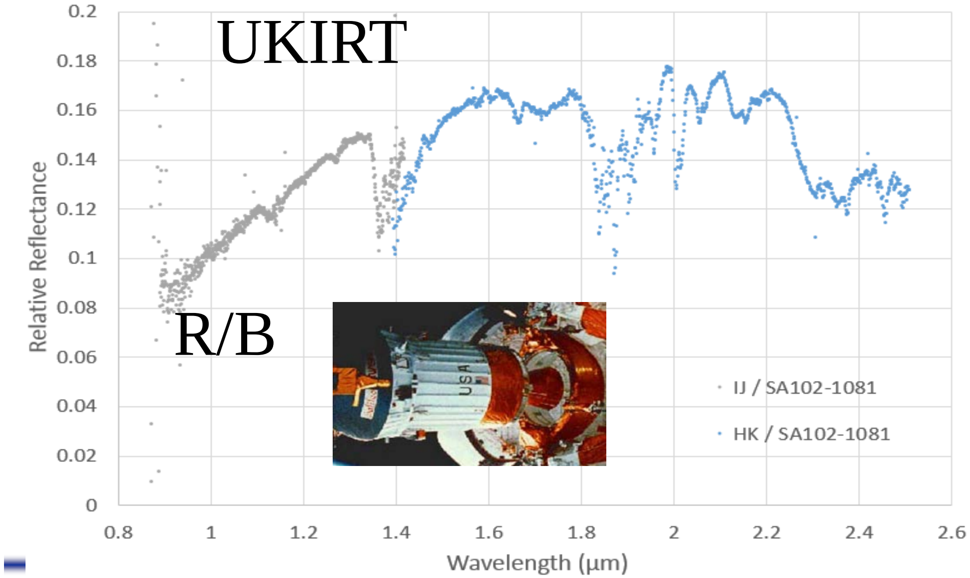
Results: Data, Models, Residual

IRTF Data from Abercromby et al. AMOS2015

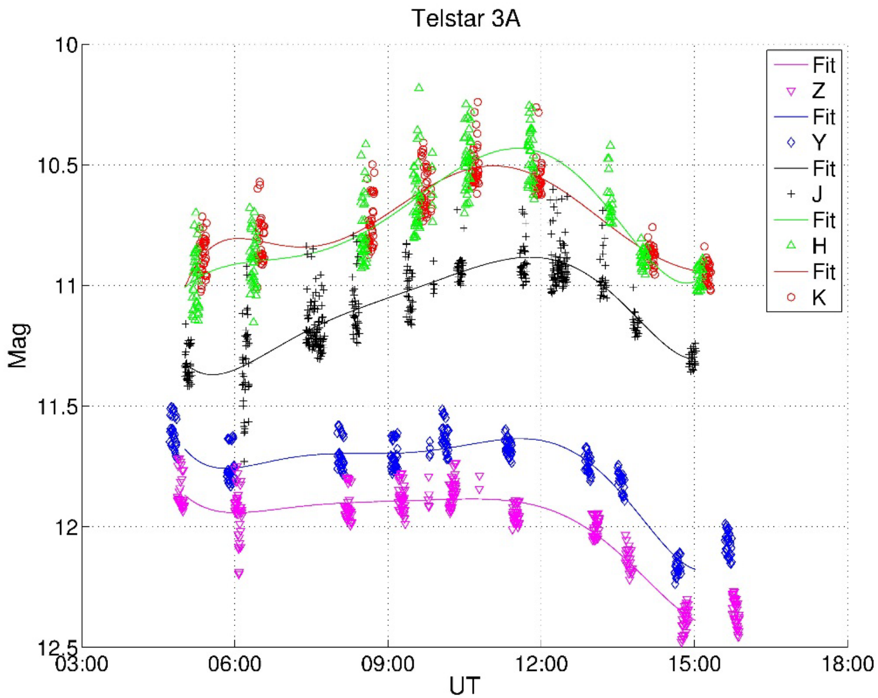


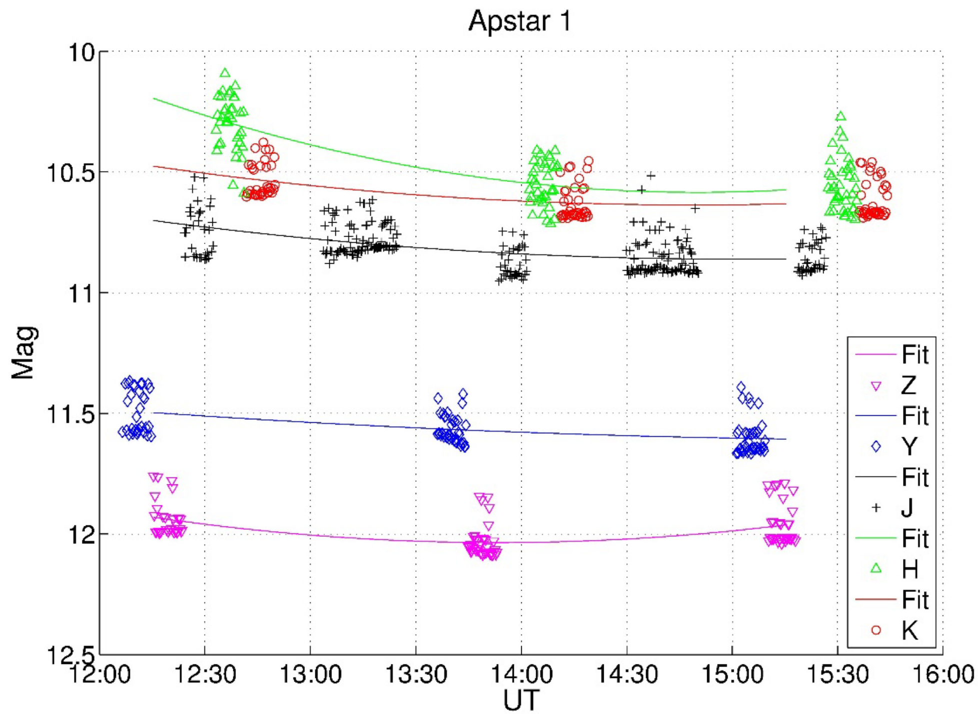




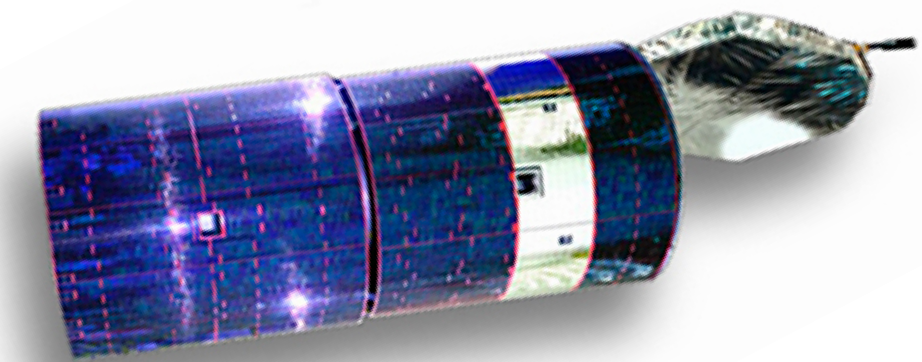


HS 376 Bus Study:



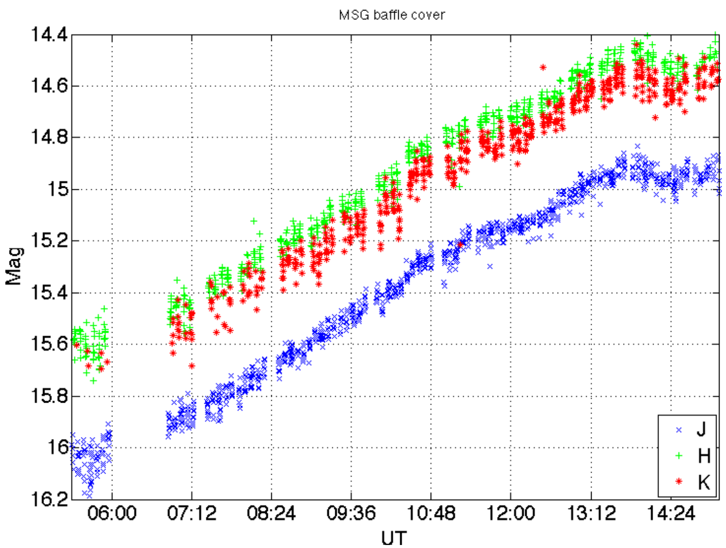


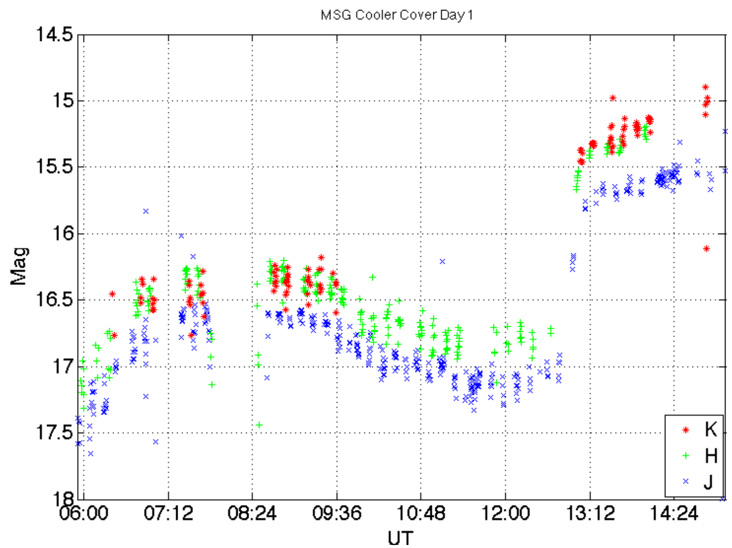
- **Investigating known shape/composition objects with respect to launch date**
  → Space weathering



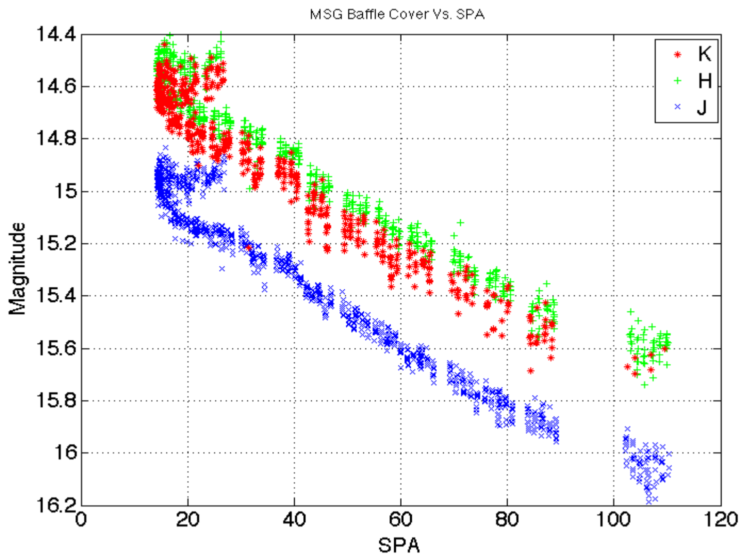
Frith et al., Amos Tech. Conf. Proc. 2015

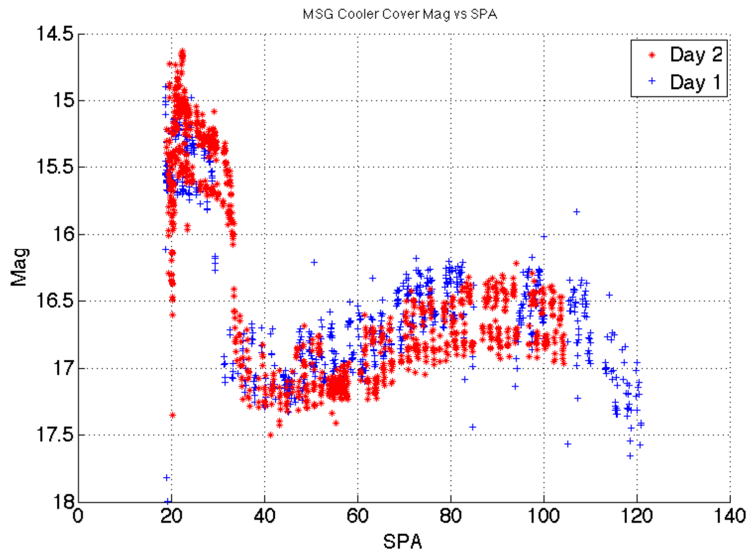
MSG Baffle Cover & Cooler Cover





vs UT





vs Solar Phase Angle

Lederer et al., Amos Tech. Conf. Proc. 2014

UKIRT data taken by Debris office

- **Dataset in hand**
  - GEO near-IR **survey data** with WFCam imager (20 nights)
  - GEO **target specific studies** with WFCam near-IR imager (LOTS)
    - HS-376 Rocket bodies
    - Titan and Ekran debris
    - Array covers, rocket bodies
  - GEO/MEO **near-IR Spectral studies** (1-2.5µm)
    - HS-376 buses (cylinders surrounded by solar panels)
    - Dead satellites (buses with wings)
    - Rocket bodies
    - Debris: Titan, Ekran, Baffle and array covers
    - Etalon at MEO
  - GEO/GTO **Thermal IR studies** – photometry and/or spectroscopy at 8-16 µm
    - HS376, buses with wings
    - Titan debris, Ariane debris

Any Questions?

Backup slides

ODPO/MCAT Objectives (BIG PICTURE)

Primary:

Distribution Function (#, size, type) for **GEO-GTO*** debris field
Achieved via sweep of inertial volume near GEO altitudes spanning inclinations expanded by solar lunar perturbations (stable plane).

Secondary:

Debris type determination through multi-band (g′r′i′z′ or BVRI) photometric or spectroscopic

Rapidly respond to break-up event – *time evolution of cloud*

Distribution Function (#, size, type) for **LEO-MEO*** debris field extending to 0º inclination – *achieved via static or orbit scan survey with subsequent tracking*
Fast tracking telescope/dome can easily track Low Inclination Leo Objects (LILO)

Tertiary:

SSA Coverage of Unique Longitude as contributing sensor of global sensor network –
Supports Space Situational Awareness (SSA) activities

Receive **target Hand-offs** from other global sensors – *better orbit determination*

Simultaneous Radar and Optical observations – *in depth assessment of debris properties*

**GEO = Geosync; HEO = High Earth Orbit; GTO = Geo Transfer Orbit; LEO = Low Earth Orbit; MEO = Middle Earth Orbit*

MCAT Objectives: Primary

- **Distribution Function for GEO (GEO Survey)**

  Achieved via sweep of inertial volume near GEO altitudes spanning inclinations expanded by solar lunar perturbations (stable plane). Patterned sweep is typically performed by counter-sidereal drift scan.

  – DATA: (flux (#/brightness), size, classification)

  – MODE 1: Geo Survey / Geo Follow-up

    - GEO Survey
      - ➢ TDI mode: Telescope tracks at the Sidereal (star motion) rate and CCD scans in the opposite direction (counter-sidereal) to track 'motionless' GEO objects
      - ➢ Search via choosing selected phase angles and about the stable plane
      - ➢ MCAT can track faster/slower during TDI mode for slightly different GEO orbits
      - ➢ → flux (number, brightness)
    - GEO Follow-up
      - ➢ Re-acquire GEO debris exhibiting longitudinal drift based on position/motion from Survey mode
      - ➢ Filter photometry → material types

  – Extension of MODEST program in Chile

MCAT Objectives: Secondary

- **Rapid response to Break-up Event**

  Time evolution of cloud

  – DATA: (metrics, multiband filter photometry)

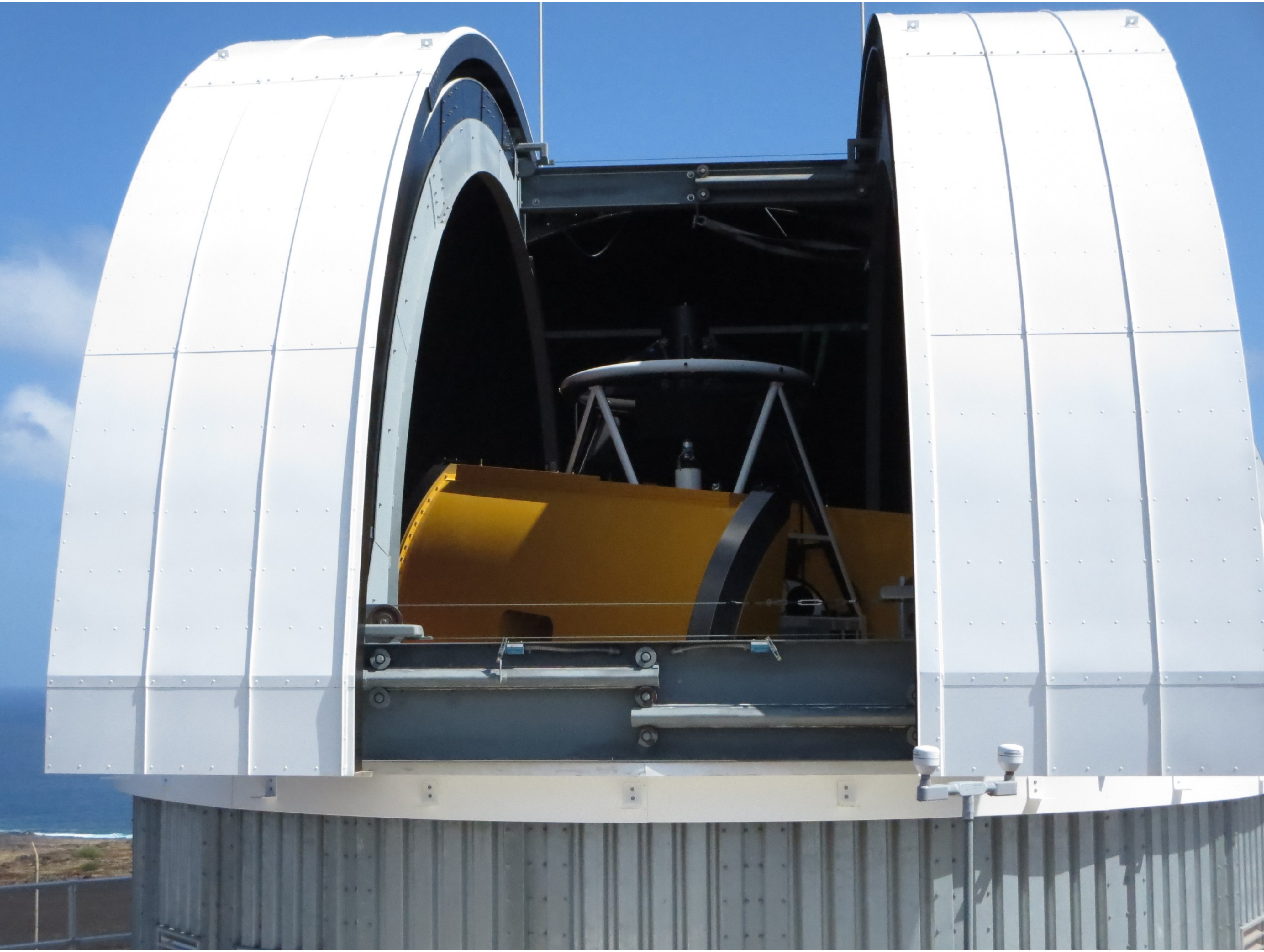
  – MODE 3: Orbit Scan
    - Scan at the expected rate of the debris cloud
    - Define rate track by a given expected orbital rate of parent body
    - Discover daughter debris
      - ➢ Metrics → orbital information
      - ➢ Multiband filter photometry → material type

- **Debris type determination:**

  Multi-band photometry (colors) or spectroscopy

  – DATA:(metrics, multiband filter photometry, [spectroscopy – future?])
    - Eccentricity and orbital variations → Area/Mass estimates → Material type
    - Photometry/Spectroscopy → Material type
    - Photometric lightcurves → tumble rates, albedo variations

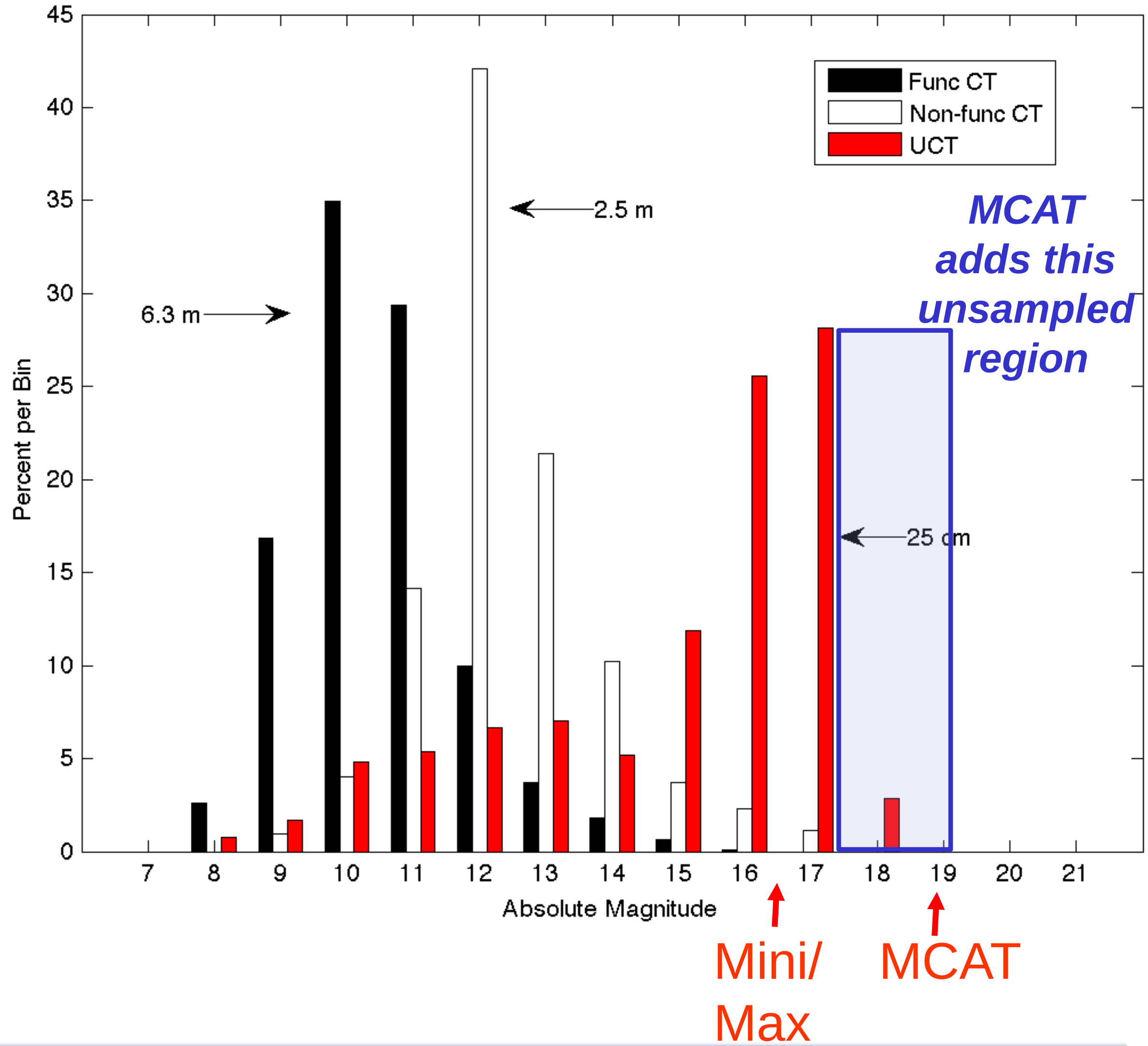
  – MODE 2: Catalogue or Object of Interest Tracking in any orbit
    - Follows object of a known orbit to characterize colors or gather spectra for material type



MCAT Performance at GEO

- **Limiting magnitude** seen by other telescopes around the world is dependent upon a variety of variables
  - Atmospheric stability (seeing)
  - Site conditions (extinction due to e.g. altitude, atmospheric aerosols)
  - Telescope through-put
  - Filter chosen
  - Telescope mirror quality

- Assume **MCAT** experiences:
  - 1.5″ seeing on Ascension
  - Telescope encircled EE 70%
  - → **18.9mag**
  - → **13cm at GEO** assuming **0.175** albedo and very good atmospheric conditions
- **miniCAT/RCAT/MAX**
  - → **16.5mag**
  - → **40 cm** at GEO with 0.175 albedo



CCD: Quantum Efficiency
Filters: BVRI and g'r'i'z'